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Photo-thermal unit requirement of wheat under different levels of irrigation

M.H. Ali[1], M.R. Hoque[2], A.A. Hassan[1] and M.A. Khair[2]
[1]Agricultural Engineering Division, Bangladesh Institute of Nuclear Agriculture, P.O. Box-4, Mymensingh, Bangladesh, [2]Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, Bangladesh

Abstract

The productivity of a crop depends on genotype x environment interaction. Temperature and light influence various physiological processes including photosynthesis and respiration; and consequently the rate and duration of growth and thus the productivity of wheat. Investigation was made on the photo-thermal unit requirement of the newly released wheat variety 'Satabdhi' under different irrigation regimes. Full irrigated wheat required more days for onset, duration and thermal units for expression of various phenophases or for maturity than that of non-irrigated one; but almost similar of the units within the treatments irrigated at 2 or 3 stages. A relatively fixed amount of heat units was needed to proceed from one phenophase to the other or sowing to maturity, irrespective of the sowing date studied. The 'growing-degree days' (GDD) and 'crop heat unit' (CHU) indices were found superior to other units in explaining wheat maturity. Heat use efficiency for production of seed yield and total dry matter production was evaluated. The highest heat use efficiency (2.26 and 6.66 kg/ha/deg.-day for seed yield and dry-matter, respectively) were obtained in well irrigated treatment, and the lowest (1.14 kg/ha/deg.-day) in full deficit treatment.

Keywords: Heat unit, Wheat, Irrigation, Thermal indices, Heat use efficiency

Introduction

The productivity of a crop depends on genotype x environment interaction. Crop productivity is inhibited at temperature higher than optimum (Gilmore and Rogers, 1958), which also affects the adaptability of a crop or variety (Wallis *et al.*, 1980). Crop development rate can be modified by several factors, such as photo-period, soil moisture, solar radiation and fertility, but it is primarily affected by temperature (e.g. Hodges, 1991; Baron et al., 1975). The efficiency of temperature utilization varies with genotype as well as the location.

Crop development is generally dependent on thermal index or heat units, and a physiological clock can be developed based on growing-degree-days. Maderski *et al.* (1973) reported that the coefficient of variation was small and half in describing the timing of physiological development of corn based on accumulated heat units, compared to the calendar-day method. Growing-degree-days have also been used to develop physiological clocks for sorghum (Arkin *et al.*, 1976), alfalfa (Holt *et al.*, 1975), cotton (Stapleton, 1970), and soybean (Major *et al.*, 1975).

Wheat is a thermo-sensitive, long-day crop, grown extensively throughout the world. The duration, growth and yield are decided by the thermal and photo-period conditions experienced by the crop during its life-cycle (Ghadekar *et al.* 1992). Temperature affects the growth of plants in numerous ways, from emergence of seedlings to maturity, influencing various physiological processes including photosynthesis and respiration; and consequently the rate and duration of growth and thus the productivity of wheat (Pal *et al.*, 1996). Heat use efficiency, i.e. efficiency of utilization of heat in terms of dry matter accumulation, depends on crop type, genetic factors, moisture availability and sowing time, and has great practical implications (Rao *et al.*, 1992, Rao *et al.*, 1999).

Thermal indices predicts and describe development rate more accurately than time in days, and are commonly used to rate wheat for maturity (Shaykewich, 1995). An ideal index would estimate a constant number of heat units for a given genotype to reach a specific development stage (Dwyer *et al.*, 1999). Phenology is an essential component of the crop-weather models, which can be used to specify the appropriate time and rate of specific phasic development processes (Singh *et al.*, 2001).

The thermal and heliothermal requirement of any crop or variety are specific for maximum yield (Cross and Zuber, 1972). Since information on requirement of thermal units of newly released wheat variety '***Satabdhi***' is meagre, investigation was made on the photo-thermal unit requirement of the same under different irrigation regimes, sown at different dates (in two contrasting weather year); as a part of a program to examine the effect of deficit irrigation regimes on wheat growth and yield.

Materials and Methods

Experimental site

Field experiment was conducted at the experimental farm of Bangladesh Institute of Nuclear Agriculture (BINA), Ishurdi, Bangladesh (co-ordinates are: latitude 24 ^{0} 06′ N, longitude 89^0 01′ E). Its altitude is 34 m above mean sea level.

Climate and water-table fluctuation

The local climate is humid and sub-tropic with summer dominant rainfall (yearly average rainfall of 1572 mm, concentrated over the months of April to September). The wheat-growing period, November to March, is characterized by dry winter. The depth to static groundwater level at the site (piezometric surface, measured in observation well) during the start of the experiment was 2.07 m from the ground level, declined gradually and reached to 4.60 m during physiological maturity of the crop.

Soil

The soil was a calcareous brown floodplain silt loam developed from Ganges river alluvium and classified as calcareous fluvisol according to FAO/UNESCO classification (FAO, 1971). The soil is of alkaline pH, medium in organic matter, and the basic infiltration rate of 0.48 cm/hr. Bulk density of the soil ranged from 1.4 to 1.6 gm/cc, and having no restricted layer within 1.2 meter. The upper and lower limits of available water were 0.45 and 0.19 m^3/m^3, respectively.

Cultivar

The wheat cultivar (*Triticum aestivum*) 'Shatabdi' was used for the experiment. It suits the prevailing climate of winter season (Nov. – March). It was developed by 'Bangladesh Agricultural Research Institute'(BARI).

Irrigation treatments

Water deficit was created by withholding irrigation at different growth stages. A non-irrigated check (T_1) and an irrigated check (T_9) were included as control treatments. Details of irrigation treatments are given in Table 1. Irrigation amount at a particular stage was equal to 80 % of the amount required to fill upto field capacity (F.C.) to the effective root zone depth (the depth within which 80 % of the roots are concentrated) .

Table 1. Details of irrigation treatments

Treatment	Irrigation at growth phase*			
	Crown root initiation (CRI)	Jointing to Shooting	Booting to Heading	Flowering to soft dough
T_1	0	0	0	0
T_2	1	1	1	1
T_3	**0**	1	1	1
T_4	1	**0**	1	1
T_5	1	1	**0**	1
T_6	1	1	1	**0**
T_7	1	**0**	1	**0**
T_8	**0**	1	**0**	1
T_9**	**1**	1	**1**	1
T_{10}	**1**	0	0	0

* '1' indicates one irrigation at this stage, and '0' indicates no irrigation (deficit).
** in addition to irrigation at each stage, irrigation will be given when total available moisture within the root zone drops below 50 %.

Unit plot and culture

Wheat seeds were sown manually in rows 20 centimeter (cm) apart, on November 6, 2002 in first year; and on Nov. 16, 2003 for 2nd year. The row orientation was north-south direction, as to facilitate favourable micro-climate (Bishnoi *et al.*, 1991). Each elementary plot was 3 m x 2.75 m, and was separated from adjacent plots within the replicates by 0.5 m in addition to 0.3 m bund. Average in-line spacing between plants were maintained 5 cm (the planting frame being 0.20 m x 0.05 m) at 20 days after sowing. Plant population density was close to 100 x 10^4 plants per hectare. Observations on different phenophases were taken. Attainment of a particular phenophase was ascertained when 50 % of the plants of the unit plot were reached to that phase. The crop was harvested manually.

Thermal unit calculation

The most common thermal indices are growing degree-days (Wang, 1960), crop heat units (Brown and Bostsman, 1993), heliothermal units (Rajput *et al.*, 1987), and photothermal units (Hundal *et al.*, 2003).

Growing-degree-days

Growing-degree-day (GDD) is widely used for describing the temperature responses to growth and development of crops. Growing-degree-days required to reach maturity are calculated following Nuttonson (1955):

$$GDD = \sum_{i=m}^{n} (T_A - T_B)\Delta t \qquad \text{.................................... (1)}$$

where, T_A is the average of daily maximum (T_{max}) and minimum (T_{min}) air temperature, T_B is a base temperature below which development is assumed to cease, *m* is date of sowing, *n* is date of physiological maturity, and Δt is a time step in days. For wheat, T_B for the entire period from sowing to maturity was considered as 5 ^{0}C (Singh *et al.*. 2001; Pal *et al.*, 1996).

Crop heat unit

Crop heat unit (CHU) was calculated by partial modification of the formula given by Cutforth and Shaykewich (1990) as:

$$CHU = \sum (X + Y)/2 \qquad \text{.. (2)}$$

where, $X = 1.8\ (T_{min} - 5)$, for $T_{min} \geq 5\ ^0C$
$= 0$, for $T_{min} < 5\ ^0C$

$Y = 3.33\ (T_{max} - 10) - 0.083(T_{max} - 10)^2$, for $T_{max} \geq 10\ ^0C$
$= 0$, for $T_{max} < 10\ ^0C$

Heliothermal unit

Heliothermal unit (HTU) was calculated by multiplying growing-degree-days with daily actual sunshine hours (Rajput *et al.*, 1987; Billore *et al.*, 1996).

$$HTU = \sum GDD.SH = \sum_{i=m}^{n} (T_A - T_B)\Delta t.SH \qquad \text{......................... (3)}$$

Where, *SH* is the daily actual sunshine hour.

Photothermal units

Photothermal units (PTU), the product of GDD and corresponding day length for that day were computed on daily basis following Hundal *et al.* (2003):

$$PTU = \sum GDD \times (\text{day length}) \qquad \text{.................................... (4)}$$

Where, 'day length' refers to maximum possible sunshine hours. Maximum possible sunshine hour was computed from solar equations following the procedure outlined by Duffy and Beckman (1984). The declination δ, as the angle of the sun north or south of the equatorial plane, is defined as:

$$\delta = 23.45 \text{ Sin } [360(284+n)/365] \quad \text{..........................} \quad (5)$$

Where n is the Julian day of the year.

After the computation of δ, the length of maximum possible sunshine or photo-period in a day (N) is obtained from the equation:

$$N = (2/15) \cos^{-1}(-\tan\delta \tan\phi) \quad \text{...........................} \quad (6)$$

Where ϕ is the latitude of a location , positive to the north; N in hour.

Heat-use efficiency

Heat-use efficiency (HUE) for seed and total dry matter was calculated following Hundal *et al.* (2003):

$$HUE = Y/ AHU \quad \text{..................................} \quad (7)$$

where, Y = Seed yield or total dry matter, Kg/ha
AHU = Accumulated heat units, degree-day
HUE is in kg/ha/degree-day

Results and Discussion

Climatological parameters

Figure 1 shows the most significant climatological data of the crop period expressed as daily values (days after sowing). It is observed that in 2003-04, the average temperature was lower to the year 2002-03 during early part of the growing season (upto 54 days from sowing) and higher during later part. Relative humidity in 2003-04 was mostly lower than that of in 2002-03. The sunshine hour was mostly lower during early parts (upto 54 days) and higher upto 100 days, and again lower after 100 days.

Thermal unit requirement

Thermal unit requirement for completion of different phenophases under different irrigation regimes are summarized in Table 2. The accumulated GDD required to reach the maturity ranged from 1749 to 1809 during 2003-04, and 1671 to 1779 in 2003-04. The full deficit treatment (T_1) required 60 degree-days less than that of the full irrigated condition (T_2, T_9) during 2002-03, and 108 degree-days during 2003-04. The other single or twice deficit treatments did not differ greatly in maturity.

Table 2. Thermal unit required to attain various phenophases as affected by irrigation treatments

Year	Treatment	GDD			HTU			CHU			PTU		
		Booting	flowering	maturity	Booting	flowering	maturity	Booting	flowering	maturity	Booting	flowering	maturity
2002-03	T_1	860	995	1749	4755	5223	9429	1370	1596	2787	9167	10595	18974
	T_2	883	1014	1809	4835	5263	9932	1410	1628	2877	9412	10798	19674
	T_3	860	995	1809	4755	5223	9932	1370	1596	2877	9167	10595	19674
	T_4	883	1014	1793	4835	5263	9794	1410	1628	2854	9412	10798	19487
	T_5	871	1023	1793	4795	5263	9794	1388	1643	2854	9280	10894	19487
	T_6	883	1014	1777	4835	5263	9667	1410	1628	2831	9412	10798	19306
	T_7	871	1023	1793	4795	5263	9794	1388	1643	2854	9280	10894	19487
	T_8	860	995	1793	4755	5223	9794	1370	1628	2854	9167	10798	19487
	T_9	871	1014	1809	4795	5263	9932	1388	1643	2877	9280	10894	19674
2003-04	T_1	839	952	1671	4464	4622	8722	1364	1550	2649	8898	10110	18235
	T_2	867	994	1779	4489	4776	9543	1409	1622	2795	9195	10568	19513
	T_3	867	994	1779	4489	4776	9543	1409	1622	2795	9195	10568	19513
	T_4	867	994	1779	4489	4776	9543	1409	1622	2795	9195	10568	19513
	T_5	867	994	1756	4489	4776	9349	1409	1662	2765	9195	10568	19240
	T_6	867	994	1756	4489	4776	9349	1409	1662	2765	9195	10568	19240
	T_7	867	985	1733	4489	4728	9159	1409	1605	2735	9195	10462	18967
	T_8	867	985	1756	4489	4728	9349	1409	1605	2765	9195	10462	19240
	T_9	867	994	1779	4489	4776	9543	1409	1622	2795	9195	10568	19513
	T_{10}	853	975	1733	4489	4683	9159	1386	1588	2735	9045	10353	18967

The average thermal unit requirement for different phenophases are tabulated in Table 3. The variation of these units between the two years are summarized in Table 4. It is revealed that the CHU and GDD are more stable than the other two units, as these two units showed lower CV and SD values (low variability signifies high precision). These two units can be used as a scale to estimate crop maturity period or to make crop calendar.

Table 3. Average thermal unit required for different phases under no deficit (T_9) and deficit condition (T_1)

Treatment	Phase	GDD	HTU	CHU	PTU
T_9	Maturity	1794	9738	2836	19594
	Flowering	1004	5020	1633	10731
	Booting	875	4662	1410	9304
T_1	Maturity	1710	9076	2718	18605
	Flowering	974	4923	1573	10353
	Booting	850	4610	1367	9033

Table 4. Measure of deviation of different thermal units required for different phenophases

Phase	Irrigation treatment	Type of deviation	Deviation of thermal unit			
			GDD	HTU	CHU	PTU
Maturity	T_9	Absolute difference	16	346	1	217
		SD	11	245	0.7	153
		CV(%)	1.3	5.2	0.1	1.6
	T_1	Absolute difference	78	707	138	739
		SD	55	500	78	523
		CV(%)	3.2	5.5	3.6	2.8
Flowering	T_9	Absolute difference	20	487	21	326
		SD	14	344	15	230
		CV(%)	1.4	6.9	0.9	2.1
	T_1	Absolute difference	43	601	46	485
		SD	30	425	32	343
		CV(%)	3.1	8.6	2.1	3.3
Booting	T_9	Absolute difference	16	346	1	217
		SD	11	245	0.7	153
		CV(%)	1.3	5.2	0.1	1.6
	T_1	Absolute difference	21	2.91	6	269
		SD	15	206	4	190
		CV(%)	1.7	4.5	0.3	2.1

The full deficit (non-irrigated) plots matured 4 to 5 calendar days earlier than the full-irrigated plots. From the weather graph (Fig. 1), it is observed that during 2002-03, the average temperature is lower than that of the year 2003-04 upto 54 days but higher after that period This pattern of temperature probably contributed to the similar calendar-day requirement for irrigated plots (123 days during 2002-03, and 121 days during 2003-04) in both the years, although the sowing date differed by 10 days, and also having contrasting weather condition. Singh et al. (2001) observed that number of days from sowing to maturity consistently reduced with subsequent delay in sowing. In our case, delayed sowing in 2003-04 (by 10 days) increase the duration of vegetative period due to occurrence of relatively cool weather condition, whereas during reproductive stage the period is curtailed due to increase in air temperature.

Crop heat use efficiency

Crop heat use efficiency (HUE) for different irrigation treatments are given in Table 5. The heat use efficiency was highest in well irrigated treatment (T_9) and lowest in full deficit treatment (T_1) for both seed yield and total dry matter, and in both the years.

Table 5. Heat use efficiency (HUE) as affected by irrigation treatments

Treatment	Seed yield HUE (kg/ha/deg.-day)		Dry matter HUE (kg/ha/deg.-day)	
	2002-03	2003-04	2002-03	2003-04
T_1	1.14	1.24	3.42	4.23
T_2	2.05	2.24	5.48	6.55
T_3	1.74	2.09	4.77	5.82
T_4	1.94	2.18	4.96	5.98
T_5	2.04	2.20	5.53	6.38
T_6	1.95	2.19	5.24	6.23
T_7	1.84	2.16	5.20	5.93
T_8	1.66	2.06	4.83	5.82
T_9	2.17	2.26	5.75	6.66
T_{10}	--	1.89	--	5.53

Summary and conclusion

From two years field observation, it is revealed that GDD and CHU are relatively constant for wheat growth and maturity. Non-irrigated plots required lower GDD and CHU than that of the irrigated plots. The HUE was highest in well irrigated plot and lowest in deficit plot.

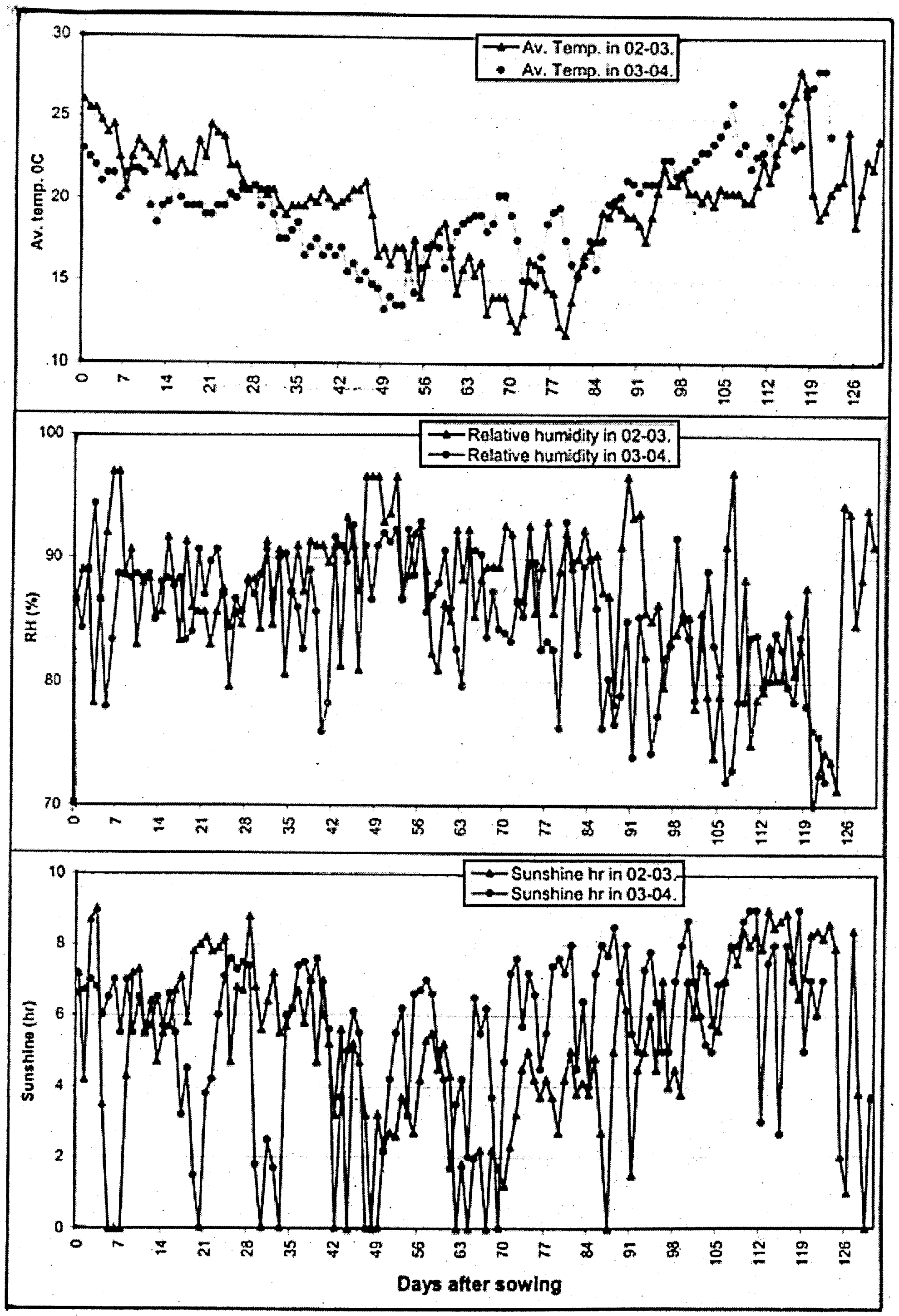

Fig. 1. Features of climatic elements during the growing seasons

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